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Physical Oceanographic Observations in the Cardigan Bay Region of Prince Edward Island 1982-1987

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ABSTRACT

Drinkwater, K. and B. Petrie. 1988. Physical oceanographic observations in the Cardigan Bay region of Prince Edward Island 1982-1987. Can. Tech. Rep. Hydrogr. Ocean Sci. 110: iv + 37 pp.

Mussels contaminated with domoic acid were found in the Cardigan Bay region of Prince Edward Island during the fall of 1987. Environmental data for the area, including water temperature and salinity, precipitation, freshwater discharge, and wind speed and direction are presented and discussed. The 1987 observations are compared to previous years' values. Precipitation is the only variable which shows a different pattern than during the previous five years. Oceanographic parameters which characterize the Bay, such as the average tidal current speed and the flushing time, are estimated.

RÉSUMÉ

Drinkwater, K. and B. Petrie. 1988. Physical oceanographic observations in the Cardigan Bay region of Prince Edward Island 1982-1987. Can. Tech. Rep. Hydrogr. Ocean Sci. 110: iv + 37 pp.

On a trouvé des moules contaminées à l'acide domoique dans la baie Cardigan (Île-du-prince-Édouard), au cours de l'automne 1987. On présente et examine ici des données concernant les caractéristiques environnementales du secteur, notamment la température et la salinité de l'eau, les précipitations, l'écoulement d'eau douce ainsi que la vitesse et la direction des vents. Ces observations, réalisées en 1987, sont comparées à celles des années antérieures. Il apparait que les précipitations sont la seule variable qui présente des différences par rapport aux cinq années antérieures. On fournit une estimation des paramètres océanographiques propres à la baie, comme la vitesse moyenne des courants de marée et le temps de renouvellement d'eau.

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INTRODUCTION

The deaths of three elderly people and the severe illness of over one hundred and fifty others in Canada during the period of November to mid-December of 1987 have been attributed to the consumption of toxic blue mussels (*Mytilus edulis L.*) harvested in eastern Prince Edward Island (P.E.I.). Most, if not all, of the contaminated mussels came from cultivated mussel farms in Cardigan Bay. The toxin, which was different from the more familiar shellfish poisons (PSP, DSP, etc.), was identified as domoic acid and is believed to have been associated with a phytoplankton bloom of *Nitschia pungens* (Bird et al. 1988). The cause of the bloom and the amount of domoic acid normally found in this particular species of phytoplankton are unknown. During the investigation into the toxic mussels several questions arose about the physical environmental conditions in the Cardigan Bay region, both generally and at the time of the outbreak of domoic acid. The purpose of this report is to review the physical oceanography of the region, to present the available physical oceanographic data, to derive some physical parameters that characterize the Bay, and to discuss, in particular, conditions during 1987. No detailed study of the Bay has been conducted but temperature and salinity data were collected, both in the Bay and in adjacent bays along the eastern shore of P.E.I., as part of monitoring programs for various biological investigations. These data will be presented following a brief description of the region, a discussion of circulation patterns and estimates of the flushing time of the water in the Bay.

STUDY AREA

The Cardigan Bay region, situated on the east coast of P.E.I., encompasses St. Marys Bay and the estuaries of the Cardigan, Brudenell, and Montague Rivers (Fig. 1). The Bay has a mean depth of 5 m with a maximum depth of 20 m at the mouth. It is one of many shallow embayments along the eastern shore. Other major bays include Boughton Bay, Rollo Bay and the Murray River estuary. The adjacent offshore

area is eastern Northumberland Strait which separates P.E.I. from Nova Scotia. The depths in the Strait range between 20 and 60 m.

CIRCULATION

The mean surface circulation in eastern Northumberland Strait was investigated by Lauzier (1965) from drift bottle experiments conducted between 1960 and 1963. He inferred a southwestward current along the coast from East Point to the Cardigan Bay region (Fig. 1). Part of this flow turned eastward, contributing to a cyclonic eddy. To the south, currents were directed northward out of Northumberland Strait towards Cardigan Bay. The recovery of drift bottles on the east coast of P.E.I. indicates there is, at least occasionally, onshore movement of water; however, it is interesting that no drifters were recovered within the Cardigan Bay region. The average drift speed of the current in eastern Northumberland Strait was 0.05 m s^{-1} (3.5 nm d^{-1}) (Lauzier 1965). This was based on the fastest third of the drifters that moved beyond 18 km (10 nm) of their release site. The southwestward flow off East Point inferred by Lauzier (1965) agrees with moored current meter data collected by Farquharson (1962) which showed a mean speed of 0.12 m s^{-1} (6 nm d^{-1}) directed towards 185° at 7 m depth over 24 d in August-September, 1958 (Fig. 1). The tongue of low salinity water extending from the Magdalen Shallows southward into Northumberland Strait that was observed by Drinkwater *et al.* (1983) during the summer of 1981 is also consistent with Lauzier's drift patterns.

Lauzier (1967) described the near bottom currents in the Gulf of St. Lawrence using seabed drifters. No seabed drifters were recovered along the east coast of P.E.I. indicating an absence of a residual onshore bottom current, i.e. there is no evidence of persistent upwelling.

The magnitude of the mean surface currents in eastern Northumberland Strait is generally of the same order as, or less than, that of the tidal currents. The amplitude of the currents associated with the M_2 tides, the major tidal constituent, is 0.1-0.2 m s^{-1}

(0.25-0.5 kn) except in the vicinity of prominent headlands, such as East Point, where they can reach upwards of 0.5 m s^{-1} (1 kn) (Farquharson 1962).

The lack of direct current measurements for the Cardigan Bay region limits our discussion of its physical oceanography. However, estimates of some physical parameters which characterize the Bay are presented using available data and some simple models.

A rough estimate of the average tidal current speed (U_{ave}) can be obtained from the cross-sectional area (A_x) of any transect perpendicular to the tidal flow and the intertidal volume (tidal prism, P) inshore of that transect. Over a flood or ebb tide

$$U_{ave} = \frac{2\ P}{A_x\ T} \qquad (1)$$

where T is the tidal period (12.42 hr). The tidal prism is given by

$$P = H\ A_s \qquad (2)$$

where H is the range of the tidal elevation and A_s is the surface area of the bay shoreward of the transect. Assuming the tidal variation is sinusoidal the maximum tidal current or amplitude (U) is related to the average current by

$$U = 0.5\ \pi\ U_{ave} \qquad (3)$$

During a mean tide the average tidal current at the mouth of Cardigan Bay is 0.05 m s^{-1} with a maximum of 0.08 m s^{-1} (Table 1). During a large tide (H = 1.8 m) U_{ave} would be 0.08 m s^{-1}. Tidal currents generally decrease towards the head of the Bay, i.e. in the river estuaries and in St. Marys Bay, although in narrow passages or shoaling areas, currents may increase.

Freshwater enters the Bay primarily via the Cardigan, Brudenell and Montague Rivers. Historically, only the discharges from the Brudenell and Montague Rivers have been monitored. The north branch of the Montague was gauged from 1919 to 1933 and beginning in 1987 the discharge from the River has been measured near the town of Montague. The Brudenell River was monitored at a site outside the town of Brudenell from 1965 to 1979 but was subsequently moved closer to the town in 1979. The monthly discharges for both rivers are given in Table 2. The discharges are on the order of 1 $m^3 s^{-1}$ for both rivers with a spring maximum of 1.5 to 2 $m^3 s^{-1}$ and a summer minimum of around 0.5 $m^3 s^{-1}$. The freshwater discharge will tend to produce a near-surface residual current but much smaller than the tidal currents. Assuming the runoff pattern for the Cardigan River is similar to that for the Brudenell and Montague Rivers and noting the similarity in the size of their drainage basins, the annual freshwater discharge into Cardigan Bay is estimated to be about 3 $m^3 s^{-1}$ or approximately 3 orders of magnitude smaller than the tidal flux at the mouth of the Bay. In addition to currents due to tides and freshwater runoff, wind-driven flows are likely to play a major role in determining the physical oceanographic characteristics of the region. In deed, the maximum currents in the Bay will likely be associated with wind events as is observed in nearby embayments such as St. Georges Bay in Nova Scotia (Drinkwater 1987). Based on that study, wind-driven currents are expected to be on the order of a 0.1-0.2 m s^{-1} but may exceed these values during extreme storm conditions.

FLUSHING TIME

The waters in coastal embayments undergo exchanges with adjacent offshore waters. These exchanges are driven by a combination of forces, including the tides, winds and freshwater runoff. The rate of exchange can be expressed in terms of a flushing time, i.e. the time required to replace the water within the embayment. Frequently the flushing time is referred to as the e-folding time, defined as the time required to decrease the volume of water in a bay to e^{-1} (about 37%) of its original volume, where e is the base of nature logarithms.

First, we consider a rough estimate of exchange due to the tides. If V_o is the volume of water originally in the bay at time t=0 then assuming instantaneous and complete mixing of the tidal prism each tidal cycle, after n tidal cycles the volume of this water still residing in the bay (V_n) is

$$V_n = \left\{\frac{V}{V+P}\right\}^n V_o \qquad (4)$$

where V is the low tide volume of the Bay (i.e. V-V_o). For Cardigan Bay $V_o = 3.9 \times 10^8$ m^3 and $P = 7.14 \times 10^7$ m^3 (Table 1). The e-folding time is 5.9 tidal cycles (3 d). Equivalent values for the Cardigan River and St. Marys Bay are approximately 4 and 2.4 tidal cycles, respectively. These generally represent lower bounds because of incomplete mixing within the appropriate regions, e.g. the water near the head of the bay or estuary may not reach the mouth during an ebb tide. In addition, some of the water which does leave during the ebb may return on the following flood tide. No data are available to assess the volume of water that is actually lost on each tidal cycle, however, the true e-folding times are likely to longer than those calculated above. In Cardigan Bay, for example, the flushing time due to tides may be closer to one to two weeks. The flushing times due to the small freshwater discharge are expected to be negligible relative to the tidal effects.

In addition to tidal exchange, the single major factor affecting residence times in the Bay is expected to be wind storms. Intense storms are capable of exchanging the Bay's volume, or large parts of it, over a day or so. Drinkwater (1987) found that in nearby St. Georges Bay, a summer storm lasting for 8 hr with a peak wind stress of about 1.2 Pa produced currents of up to 0.5 m s^{-1} throughout the Bay, strong inflow and outflow at the mouth, and local mixing within the Bay. Similar responses could be expected for Cardigan Bay.

In summary, Cardigan Bay most likely undergoes periods of gradually exchange due to tides and freshwater discharge interrupted by major exchanges due to storms.

AVAILABLE OCEANOGRAPHIC OBSERVATIONS

Four separate oceanographic data sets exist for the Cardigan Bay region or in adjacent embayments along the east coast of the Island. The P.E.I. Dept. of Fisheries has routinely collected temperature and salinity data weekly to bi-monthly in the Cardigan, Boughton, Montague and Murray Rivers, and for St. Marys Bay, from 1982 through 1987 (Table 3, Fig. 1). The data were taken at up to 3 depths per site (surface, mid-depth, and bottom) and nominally cover the period from May to November. Moored temperature data using Ryan thermographs have been collected in eastern P.E.I. as part of a long-term monitoring program by the federal Department of Fisheries and Oceans since the early 1980s (Table 4). In 1987 temperature records were obtained during the summer in the Murray, Cardigan, and Boughton Rivers (Table 5). During 1987 current and temperature data were also collected using an Aanderaa current meter moored in Boughton River from June through September (A. Mallet, Bedford Institute of Oceanography, personal communication). Unfortunately, the current data were unusable, only the temperature observations were of good quality. Temperature and salinity data from the Boughton, Murray, Cardigan and Seal Rivers were collected from July to November, 1987, by members of the Atlantic Veterinary College at the University of Prince Edward Island (Table 6).

Salinities presented in this report were determined using either a YSI (Yellow Springs Instrument) salinometer or a hydrometer. Correspondence with those who collected the data indicated that their accuracy was about 1 ppt (part per thousand).

TEMPERATURE AND SALINITY

The surface and bottom temperature and salinity data collected by the P.E.I. Dept. of Fisheries within the Cardigan Bay region (from Cardigan and Montague Rivers and St. Marys Bay) are shown in Figures 2 and 3. For completeness, additional data from mid-depth at these sites together with data from Boughton and Murray Rivers are shown in the Appendix (Fig. 1A, 2A, 3A). The temperature plots show seasonal warming and cooling with a peak in mid-summer near 20°C. Superposition of the plots indicates that in general surface waters are slightly warmer (usually less than 1°C) than subsurface waters. Salinity typically varies between 20 and 30 ppt with a less distinct seasonal curve than that for temperature. The magnitudes and temporal variations of temperature and salinity between surface and bottom at each site as well as between sites are similar. Also there is noticeable interannual variability. Salinity, for example, appears to have had a minimum during 1983 and since then has slowly increased (Fig. 3). This also appears to be true for the Boughton and Murray Rivers (Appendix, Fig. A2, A3).

The average seasonal cycles for temperature were determined using a least squares fit to a sinusoidal function having a period of 1 year. The uncertainty of the data and its greater high-frequency variance made this exercise less useful for salinity. Therefore, we have not shown the seasonal cycles of salinity. The seasonal cycles for the surface and bottom depths are shown in Fig. 4. As data were collected between May to November, only these months are shown. Anomalies relative to the average seasonal cycles were then calculated (Fig. 5) for each year. A similar analysis was carried out on the mid-depth temperatures in the Cardigan Bay region and for Broughton and Murray Rivers; the results are found in the Appendix (Fig. A4-A7).

As expected the average seasonal temperature curve shows an increase during the spring and early summer, a peak between 18° and 20°C in early to mid-August, and a rapid decline in the fall. This is

typical of the southern Magdalen Shallows region (Lauzier et al. 1957).

Similar anomaly patterns were observed at the surface and bottom for each site as well as between sites both within the Cardigan Bay region (Cardigan River, Montague River and St. Marys Bay) and outside (Boughton and Murray Rivers) (Fig. 5, A4-A7). This is especially noticeable in temperature during 1982, 1983 and 1984 when the sampling frequency was greatest at all of the sites. The temperature anomalies in 1987 at the surface fluctuated between positive and negative values by about 2 to 3°C. Neither positive nor negative anomalies appeared to dominate. During 1987 negative anomalies were generally more evident near bottom. Overall the temperature anomalies during 1987 are comparable to those of previous years and not at all unusual.

The similar temperature response along the east coast of P.E.I. during 1987 is also evident in the moored data sets from the Ryan recorder and the Aanderaa current meter (Fig. 6,7). Of particular note are the rapid decreases in temperature beginning near days 182, 209, 237, and 269. These are most prominent near bottom at Boughton River, both in the Ryan and current meter records, but at times are also evident at other sites.

Other shallow Ryan records which partially covered the same period are presented in the Appendix (Fig. A8). They include time series from Murray River (1 and 6 m) and Cardigan River (surface) on the east coast of P.E.I., St. Peter's Bay (3 m) and March Water (5 m) on the north coast, and Dunk River (1 m) on the south coast (Table 5). The records clearly show that a similar response occurred around day 235 at all sites and about day 269 at those sites where data were available (Murray River, March Water and Dunk River). The comparison for day 182 shows no response at March Water and Dunk River (no data at St. Peter's Bay), a small response at Murray River and a questionable response at Cardigan River. For day 209 the response was questionable at Murray, Cardigan and Dunk Rivers and was not present at St. Peter's

Bay or March Water. The temperature data thus provide evidence of both broad scale and localized responses.

Rapid temperature decreases followed by relatively slow increases are similar to the responses observed in St. Georges Bay to wind forcing (Drinkwater 1987). To examine the importance of local wind forcing along the east coast of P.E.I. we obtained the nearest available wind records. These were collected at the lighthouse at East Point, P.E.I. Wind stresses were calculated using the formulation of Smith and Banke (1975) and are plotted in Fig. 8. The peak stress shown corresponds to a wind speed of about 15 m s^{-1}. Cross spectral analysis of the wind stress components and temperature data were carried out and coherence and phases calculated. Coherence is a frequency-dependent correlation and the phase is a measure of the time delay between the input (wind stress) and output (temperature) signals. Coherences were generally low and not significant at all frequencies investigated (periods 0.3-10 d). These results may, in part, be due to the highly non-stationary nature of the wind data, i.e. winds in summer are generally weak, broken occasionally by periods of intense storms. The predominance of weak winds will produce at best a "weak" average temperature response to wind forcing resulting in a low signal-to-noise ratio. Thus, in spite of the statistical results the periods of strong winds still may induce a significant temperature response. To determine if the 4 temperature events observed in 1987 were possibly due to wind forcing, the wind and temperature time series plots were compared. No wind event appeared to correspond to the temperature change which occurred around day 182. There were strong winds about the time of the next two large temperature changes but preceded them by about 1.5 d; i.e. they may not be linked as cause and effect. Wind events centered on day 269 and 271 could have produced the temperature response at Boughton and the other sites beginning on day 269.

The interannual variability of the salinity anomalies at all sites show a general pattern of minimum during 1983 followed by a steady increase through to 1986. It is interesting to note that 1983 corresponds to the highest total precipitation in eastern P.E.I. for

the period May to November between 1982 and 1987 (Table 6). Temperature and salinity data collected by the P.E.I. Dept. of Fisheries and the Atlantic Veterinary College in 1987 are shown in the Appendix (Fig. A10), however, due to difficulties with the salinometer the accuracy of the data is in doubt.

OTHER ENVIRONMENTAL DATA

In our investigation of possible anomalous environmental conditions in eastern P.E.I. during the fall of 1987 that might be linked to the outbreak of domoic acid in the mussels, we also considered precipitation, freshwater discharge, and winds. The 1987 precipitation observations were found to be different from the other recent years (Table 6). The June-August period was the driest by nearly 100 mm (67% below normal) while the September-November period was the wettest by over 100 mm (64% above normal). The dry summer was reflected in the freshwater discharge rates for the Brudenell River which were 30% below normal during June to August. However, the wet conditions that prevailed from September to November were not seen in the runoff of the Brudenell River. Discharge remained 25% below normal during September and October and returned to normal by November. The drier-than-average conditions in the summer likely meant that much of the excess precipitation received in the autumn was retained over the land.

The winds at East Point during 1987 were compared with their long-term means (1978-1986) and the results summarized in Table 7. The monthly mean wind speeds in 1987 were near average except during December when it was above normal. The wind variability, as measured by the standard deviation, was generally less than normal. The maximum observed winds in 1987 were below the peak winds observed during the period 1978 to 1986 for May to October. In November and December of 1987 the highest observed wind speeds matched and exceeded, respectively, the previous record highs for those months. No significant shifts in the wind directions were noted during 1987 relative to the 1978-86 mean distributions.

DISCUSSION

The data which have been assembled for the Cardigan Bay region indicate that the water temperatures during 1987 were close to their seasonal norms. Salinity data were not available for the region, however, the precipitation data for the period 1982-1987 show that the summer months (June-August) were the driest on record and the fall months (September-November) were the wettest. River runoff during the fall period of 1987, however, was below average. Mean winds were generally near normal while wind variability was below normal. There is little in the environmental observations shown here to indicate extraordinary oceanic conditions in eastern P.E.I. during the fall of 1987 that might have lead to the phytoplankton bloom and the outbreak of domoic acid.

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TABLE 1. Parameters pertaining to the calculation of the tidal currents during a mean tide at the mouth of Cardigan Bay.

H, the tidal range	1.1 m
A_s, the surface area of the Bay	6.49×10^7 m^2
P, the tidal prism	7.14×10^7 m^3
A_x, the cross-sectional area	6.67×10^4 m^2
U_{ave}, average speed of the tidal current	0.05 m s^{-1}
U, the amplitude of the tidal current	0.08 m s^{-1}

TABLE 2. The monthly mean freshwater discharge (m^3 s^{-1}) for the Brudenell River at Brudenell (1979-1986) and the North Branch of the Montague River (1919-1933).

Month	Brudenell River	Montague River
January	0.88	1.13
February	0.86	1.60
March	1.01	1.85
April	1.50	2.10
May	1.15	1.58
June	0.83	0.91
July	0.62	0.69
August	0.54	0.60
September	0.47	0.62
October	0.49	0.67
November	0.65	0.80
December	0.89	0.83

(Taken from Environment Canada. 1987. Historical Streamflow Summary Atlantic Provinces to 1986. Inland Waters/Land Directorate, Water Resources Branch, Water Survey of Canada, Ottawa, 260 p.)

TABLE 3. Location of temperature and salinity stations occupied by the P.E.I. Dept. of Fisheries between 1982 and 1987.

Site	Lat. (N)	Long. (W)	Bot. Depth (m)
Boughton Bay	46°16′00"	62°28′00"	6.4
Cardigan River	46°13′36"	62°33′18"	6.4
Montague River	46°11′30"	62°33′18"	6.0
St. Marys Bay	46°07′48"	62°30′42"	4.6
Murray River	46°02′00"	62°33′36"	4.3

TABLE 4. Ryan recorder data collected in eastern P.E.I. during the 1980s.

YEAR	.J..F..M..A..M..J..J..A..S..O..N..D.	Location	Depth (m)
1983	*****	Souris	19
	**********		19
1984	**********	Murray R.	2
	**********	Fortune R.	1.5
	**		3.5
	*******	Souris	19
1985	**********	Murray R.	1.5
	**********	Fortune R.	2.5
	**********	Souris	19
1986	**********	Murray R.	1
	******	Fortune R.	0.3
	******		6
	********	Fishermans	2
	********	Bank	12
	********		25
	******		26
	******	St. Peters Bay	1
	**********	Souris	19
1987	**********	Murray R	6
	**********		28
	**********	Boughton R.	1
	**********		5
	*******	Fortune R.	1.75
	**		2
	*******	St. Peters Bay	10
	**********	Cardigan R.	0
	**********		2

TABLE 5. Location of Ryan thermograph stations operating during the summer of 1987.

Site	Latitude (N)	Longitude (W)
Boughton River	46°15′	62°28′
Murray River	46°01′	62°35′
Cardigan	46°14′	62°44′
St. Peters Bay	46°26′	62°46′
March Water	46°31′	63°27′
Dunk River	46°23′	63°46′

TABLE 6. Precipitation in mm measured at East Baltic, P.E.I.

Year	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1982	82.0	138.8	90.5	84.4	91.2	48.4	91.6	626.9
1983	156.8	70.0	128.4	118.8	142.6	71.4	140.6	828.6
1984	98.6	89.4	41.4	186.1	116.0	77.0	108.0	717.0
1985	113.9	210.0	76.2	104.8	30.0	104.8	98.0	737.7
1986	60.2	113.8	156.6	103.0	100.7	76.2	117.4	727.9
1987	48.0	120.2	51.8	46.9	181.8	138.6	144.0	731.3

Year	June-August	September-November
1982	313.7	231.2
1983	317.2	354.6
1984	316.9	301.0
1985	391.0	232.8
1986	373.4	294.3
1987	218.9	464.4

TABLE 7. Statistics of East Point winds (m s^{-1}).

		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean speed	(1987)	6.1	5.6	5.5	4.9	6.8	6.5	8.3	10.5
	(1978-86)	5.5	5.7	5.3	5.1	6.3	7.2	8.2	8.1
Std. Dev.	(1987)	2.9	2.9	2.5	2.6	3.4	3.5	4.6	5.7
	(1978-86)*	3.8	3.7	3.4	3.7	4.0	4.5	4.8	5.0
Max. Obs.	(1987)	16.9	18.1	15.8	13.9	18.6	17.5	24.2	26.7
Speed	(1978-86)*	21.4	21.4	25.7	21.4	21.4	25.7	25.7	25.7

* The standard deviations and maximum observed wind speeds for the period 1978-86 were calculated from summary statistics grouped in bins of approximately 10 km h^{-1}.

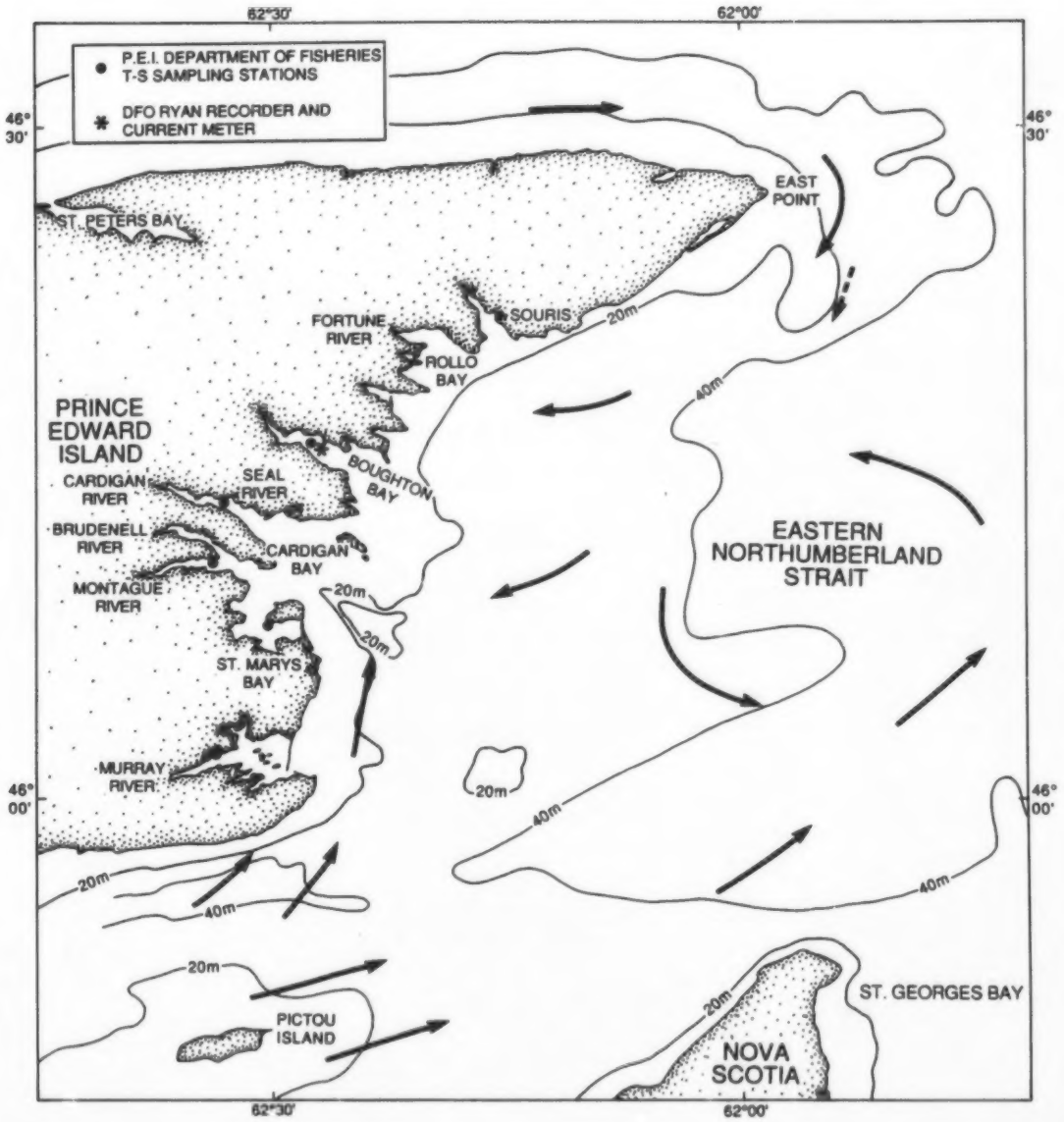


Fig. 1. The study area. The surface circulation pattern as inferred by Lauzier (1965) is shown as solid arrows. Current meter data collected by Farquharson (1962) is shown as a broken arrow depicting the mean current of 0.12 m s^{-1}. The locations of P.E.I. Dept. of Fisheries temperature and salinity sampling stations are indicated.

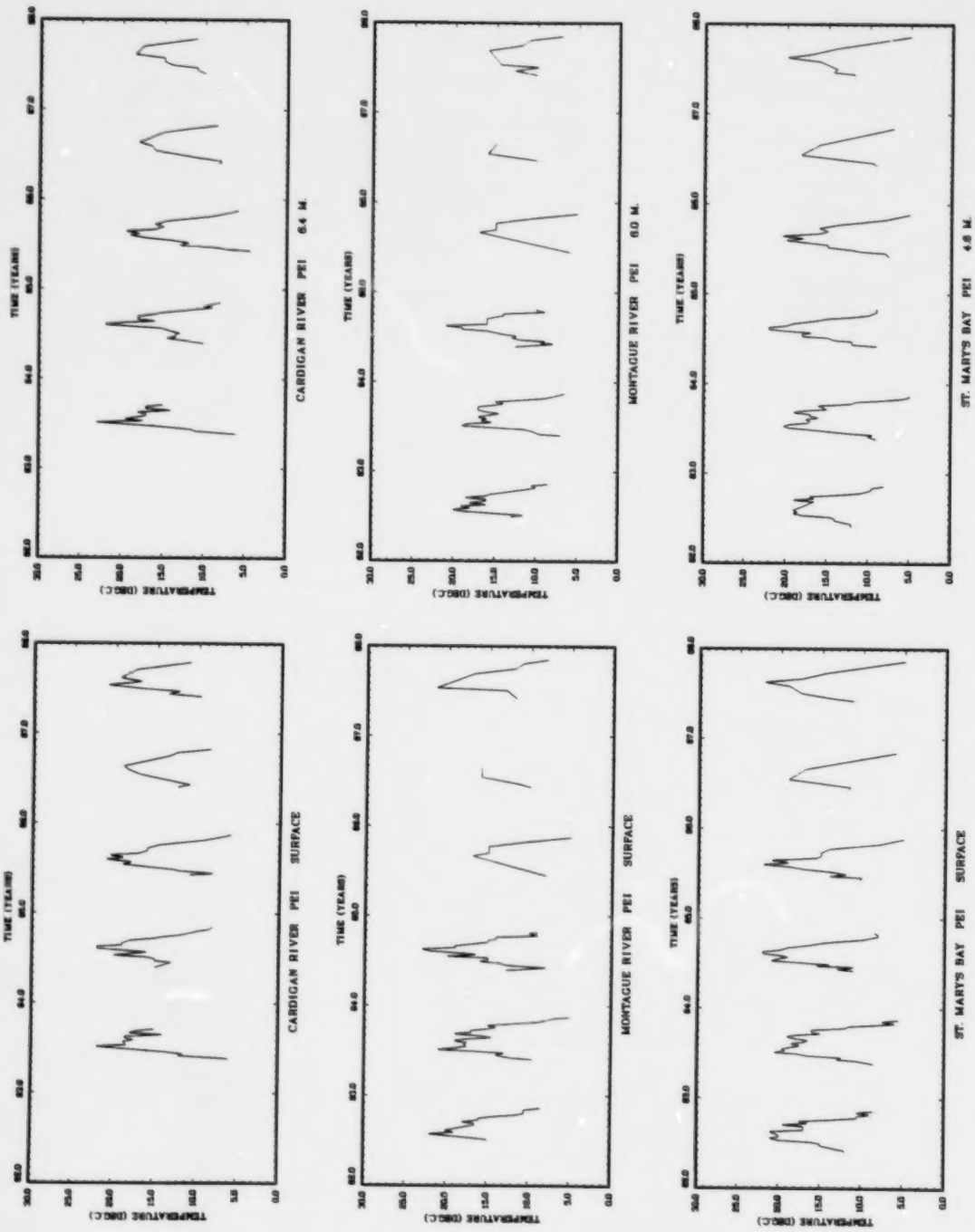

CARDIGAN RIVER PEI SURFACE
CARDIGAN RIVER PEI 6.4 M.
MONTAGUE RIVER PEI SURFACE
MONTAGUE RIVER PEI 6.0 M.
ST. MARYS BAY PEI SURFACE
ST. MARYS BAY PEI 4.6 M.
TIME (YEARS)
TEMPERATURE (DEG.C)

Fig. 2 Temperature data at the surface and near bottom for the Cardigan River, Montague River and St. Marys Bay.

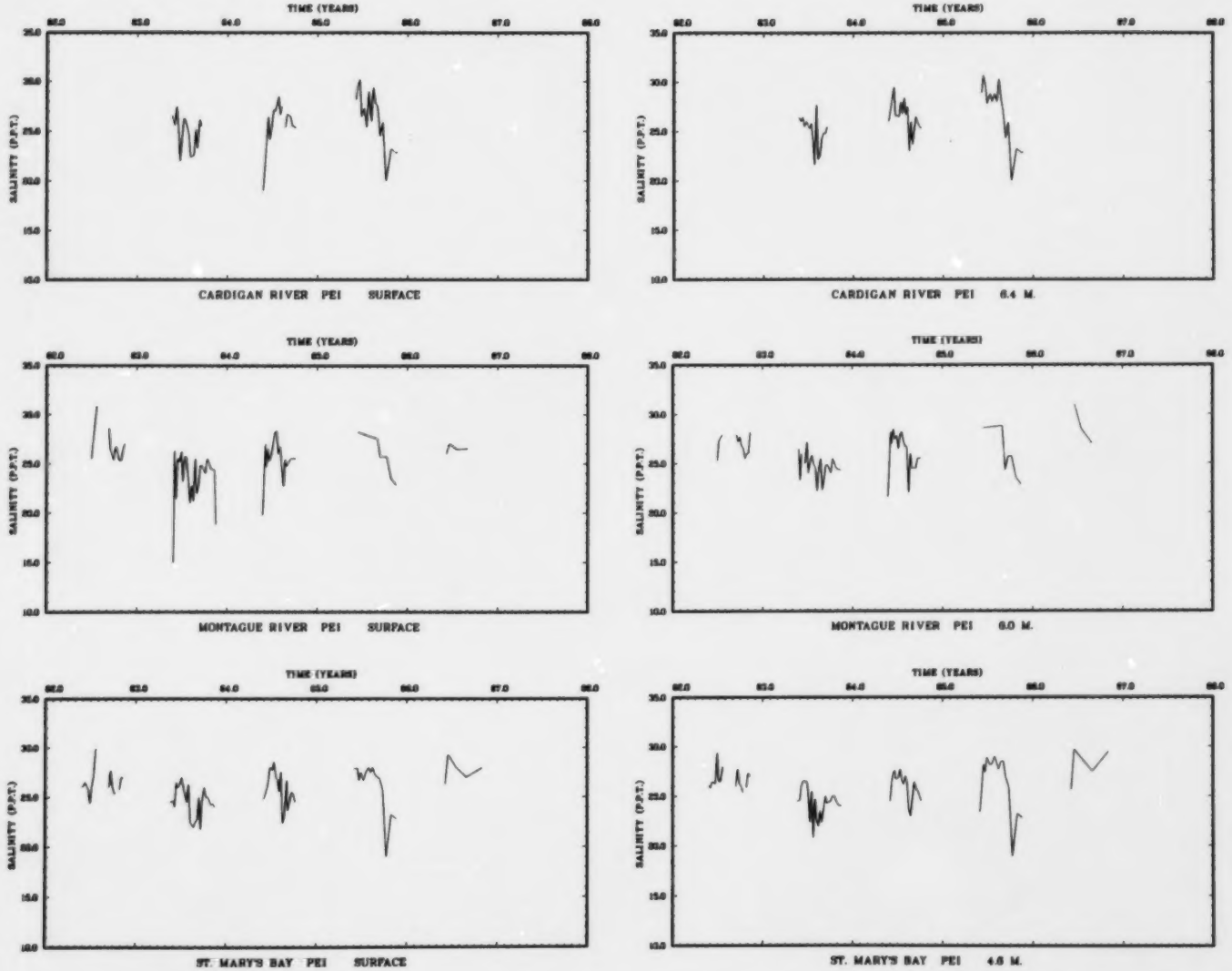

TIME (YEARS)
SALINITY (P.P.T.)
CARDIGAN RIVER PEI SURFACE
CARDIGAN RIVER PEI 6.4 M.
MONTAGUE RIVER PEI SURFACE
MONTAGUE RIVER PEI 6.0 M.
ST. MARY'S BAY PEI SURFACE
ST. MARY'S BAY PEI 4.6 M.

Fig. 3. Salinity data at the surface and near bottom for the Cardigan River, Montague River and St. Marys Bay.

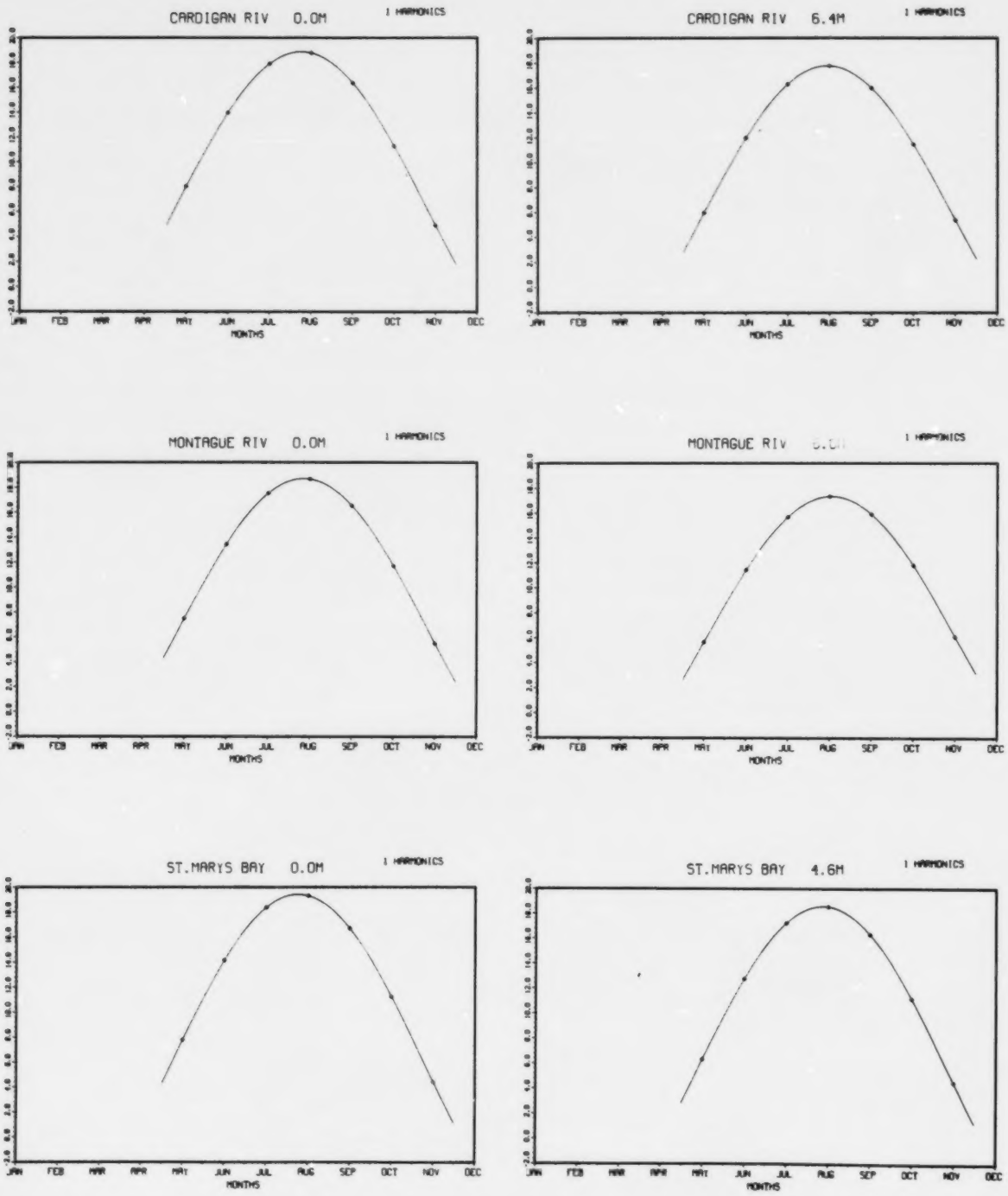


Fig. 4. Sinusoidal fit of data shown in Fig. 2 for the period May-November. The sinusoid has a period of 1 year.

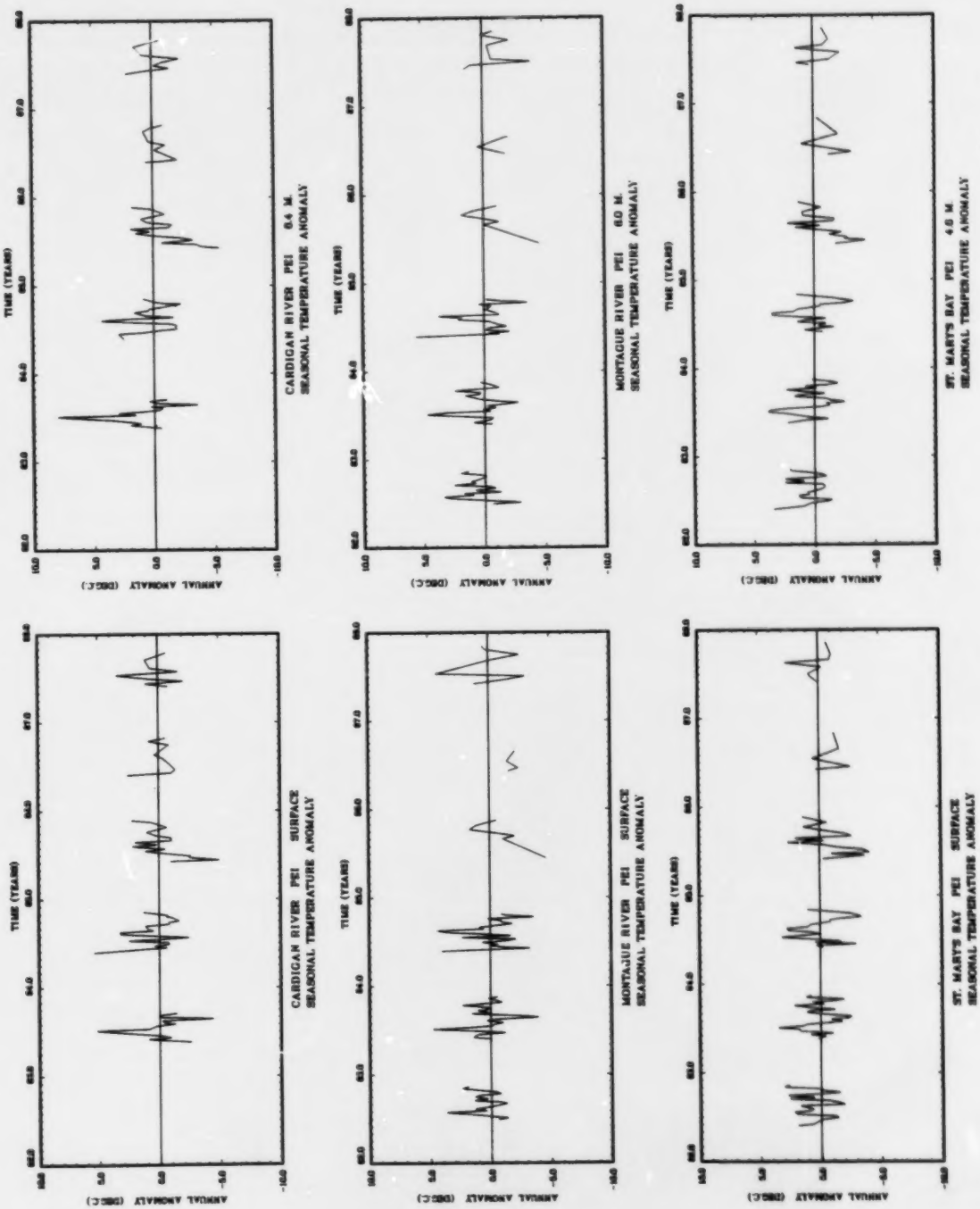
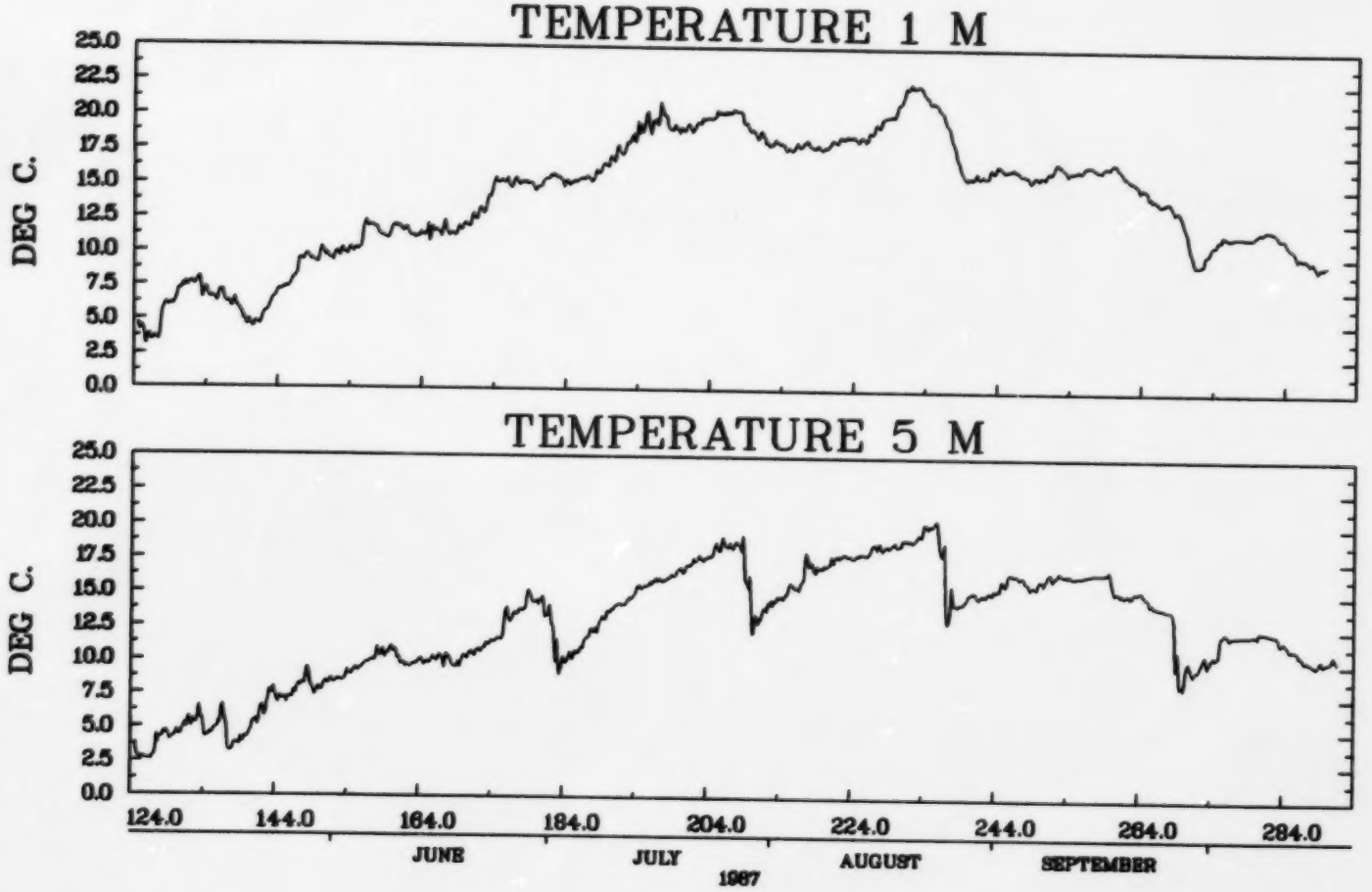


Fig. 5. Temperature anomalies relative to the period 1982-87 for Cardigan River, Montague River and St. Marys Bay.



BOUGHTON RIVER RYAN THERMOGRAPH

Fig. 6. Time series of temperature from Ryan recorders moored in Boughton River in 1987.

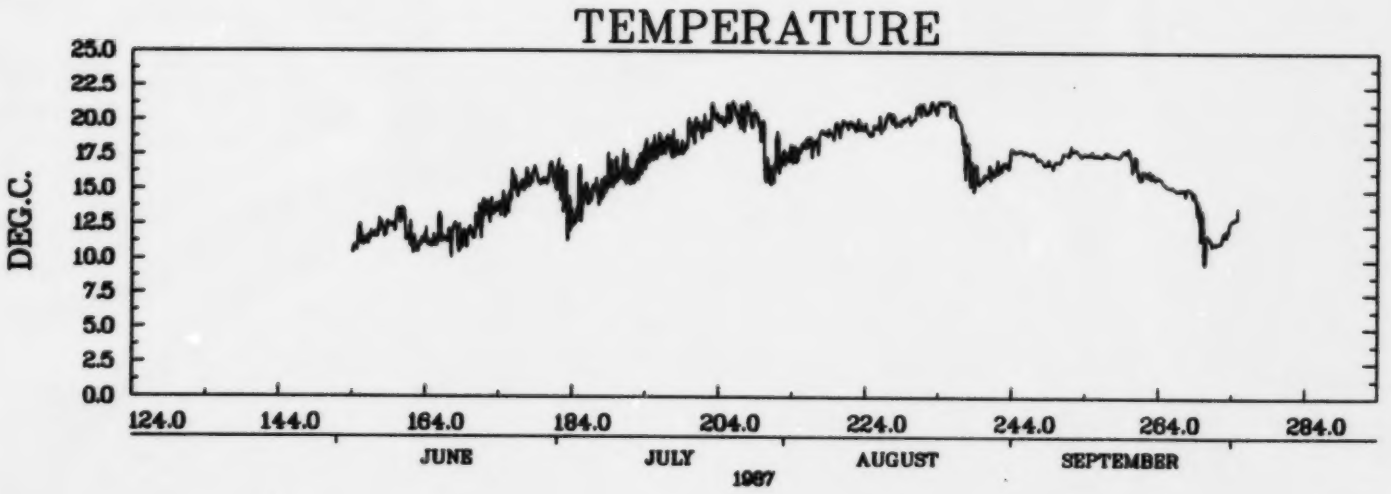
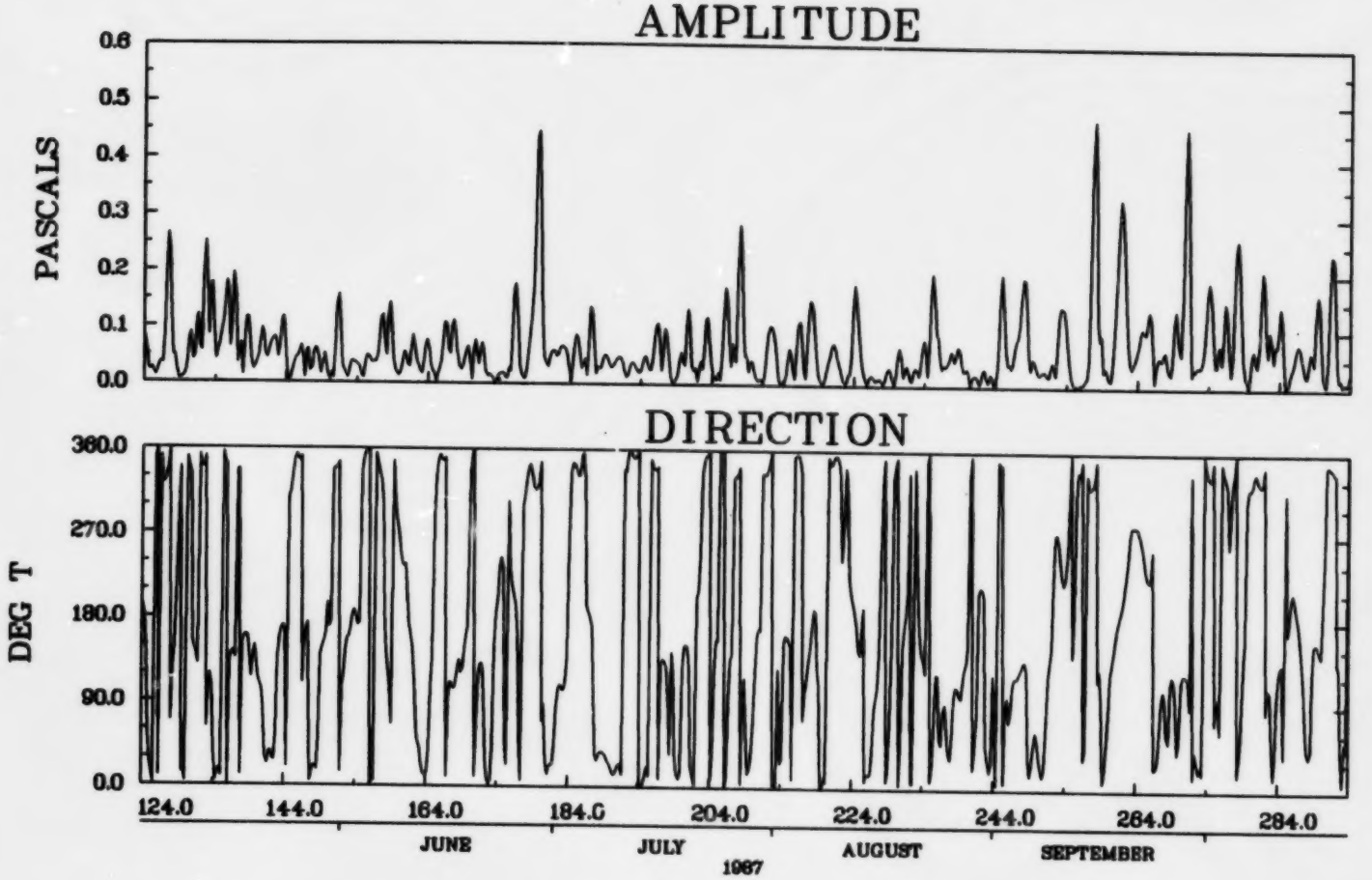


Fig. 7. Time series of temperature from a current meter moored in Boughton River in 1987 (courtesy of A. Mallet).



EAST POINT WIND STRESS

Fig. 8. Wind stress based on winds from East Point, P.E.I., 1987. The time series has been filtered using a Cartwright low pass filter with a half power point at 31 h.

APPENDIX

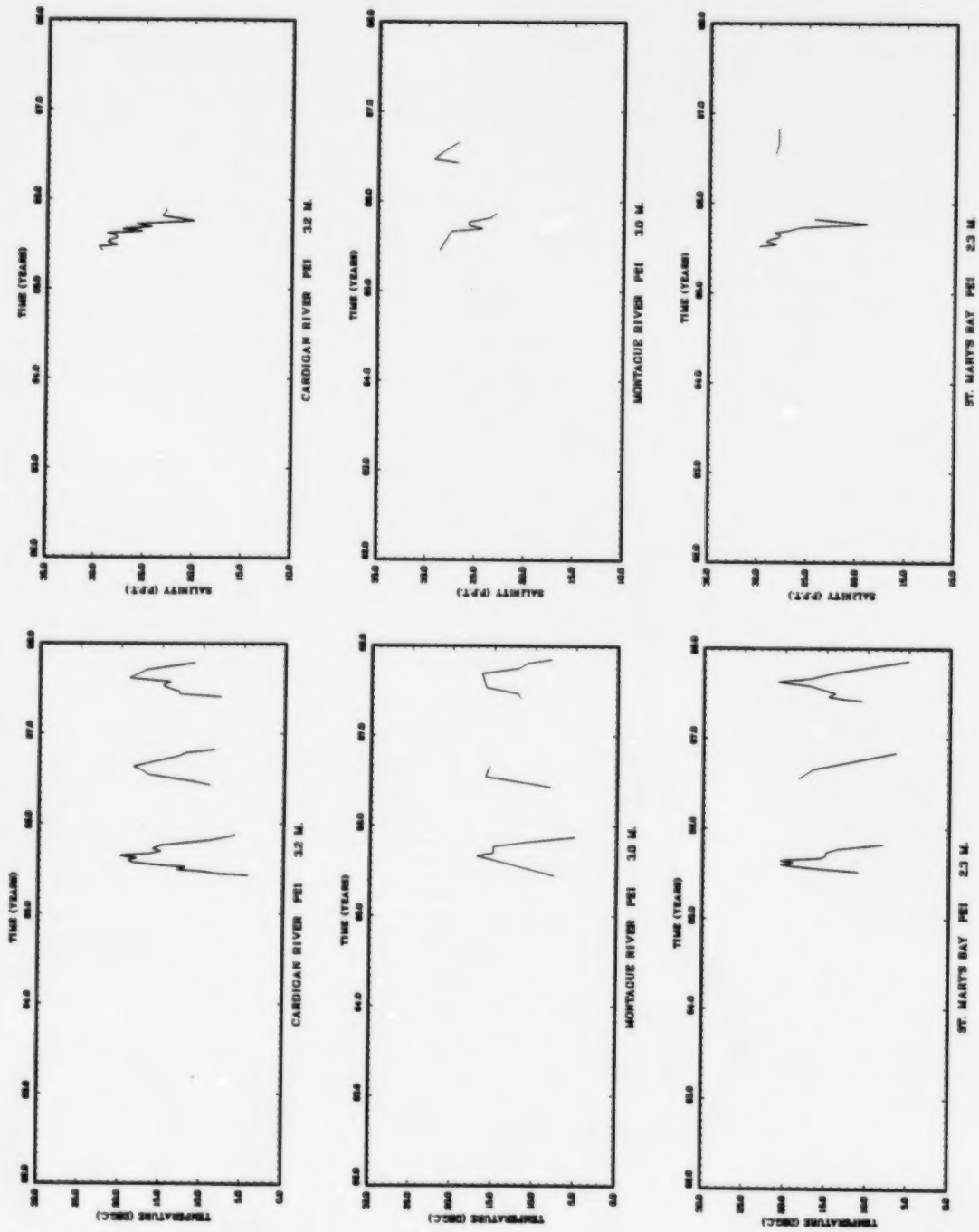


Fig. A1. Temperature and salinity data at mid-depth from Cardigan River, Montague River and St. Marys Bay.

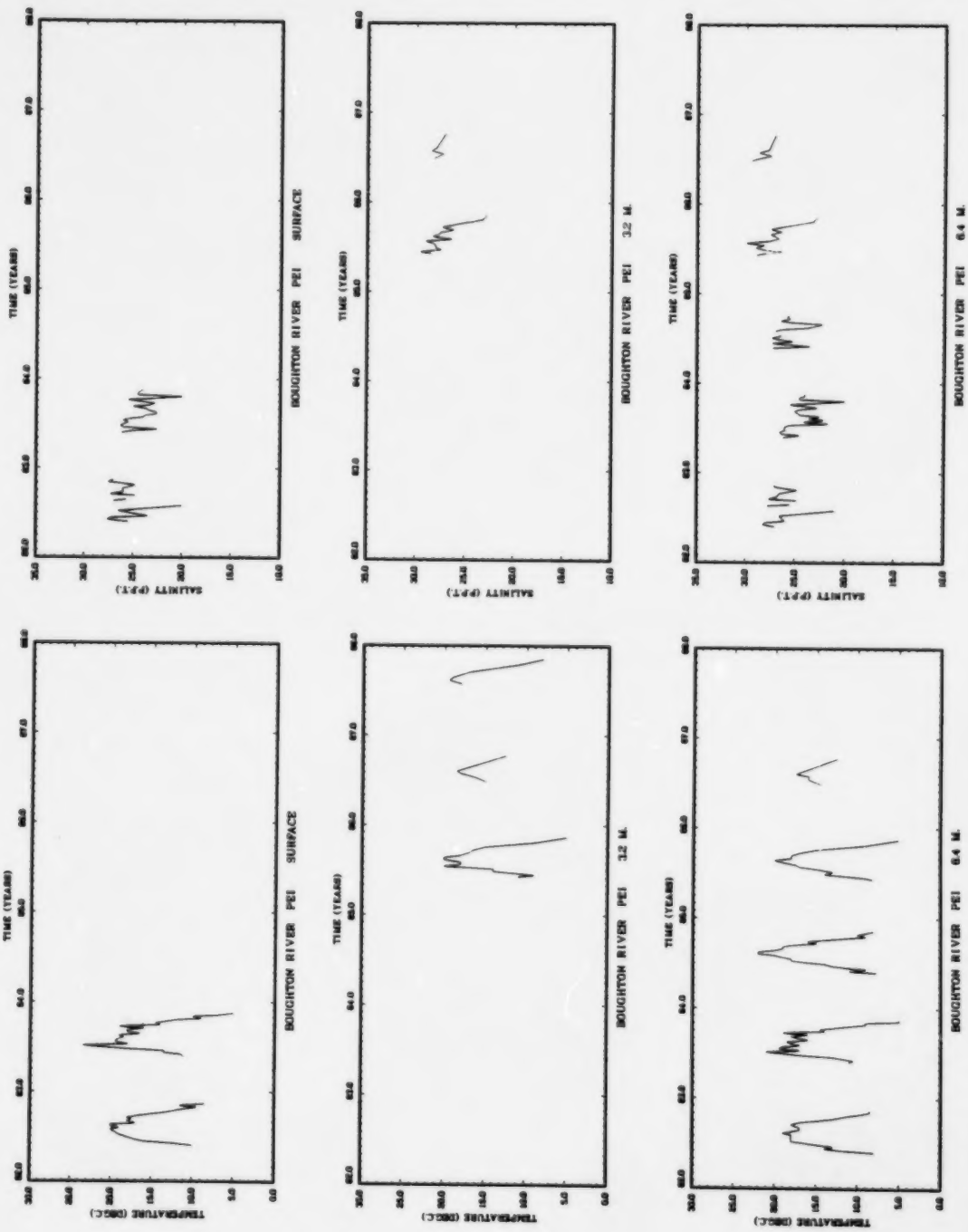


Fig. A2. Temperature and salinity data at 3 depths from Boughton River.

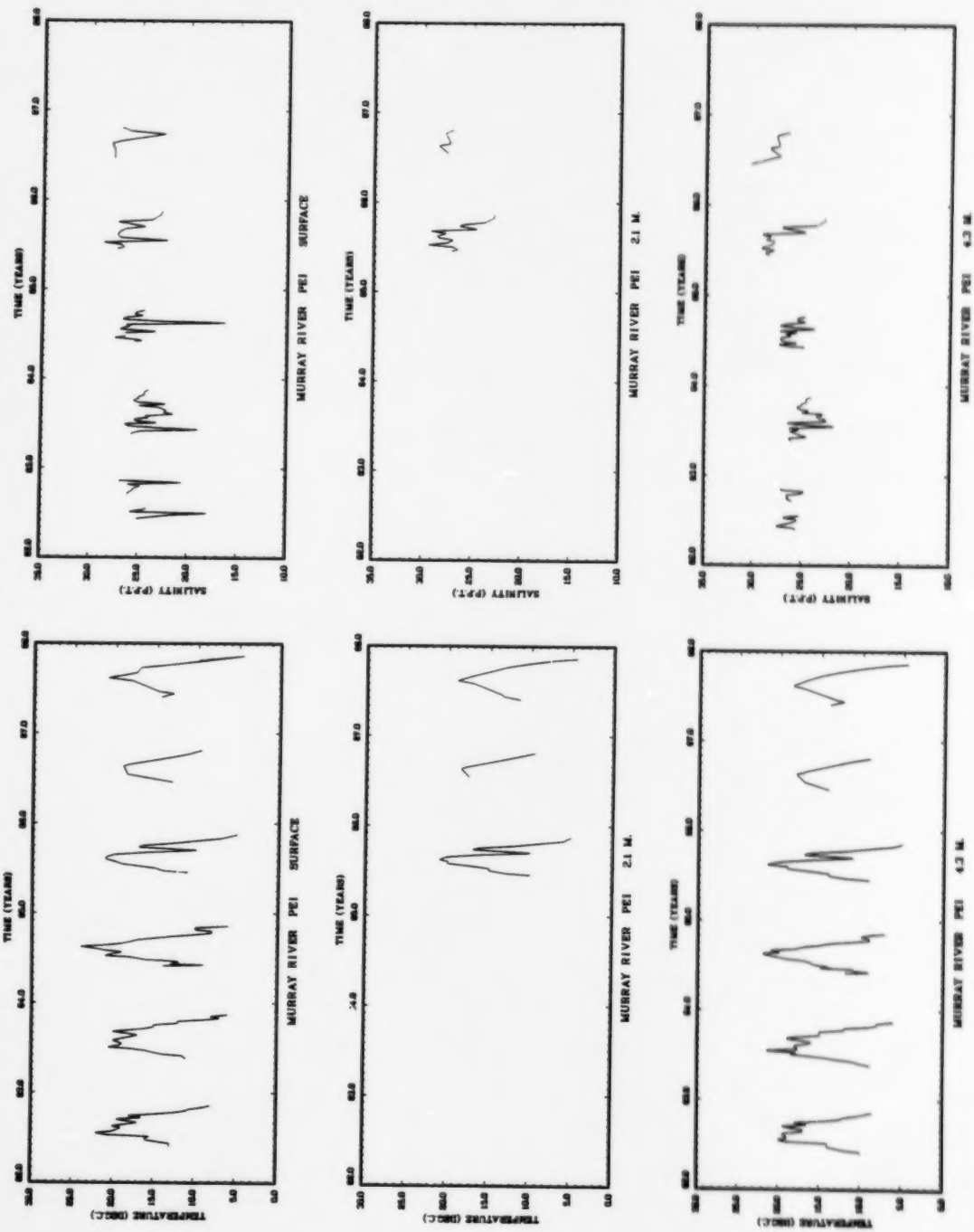


Fig. A3. Temperature and salinity data at three depths from Murray River.

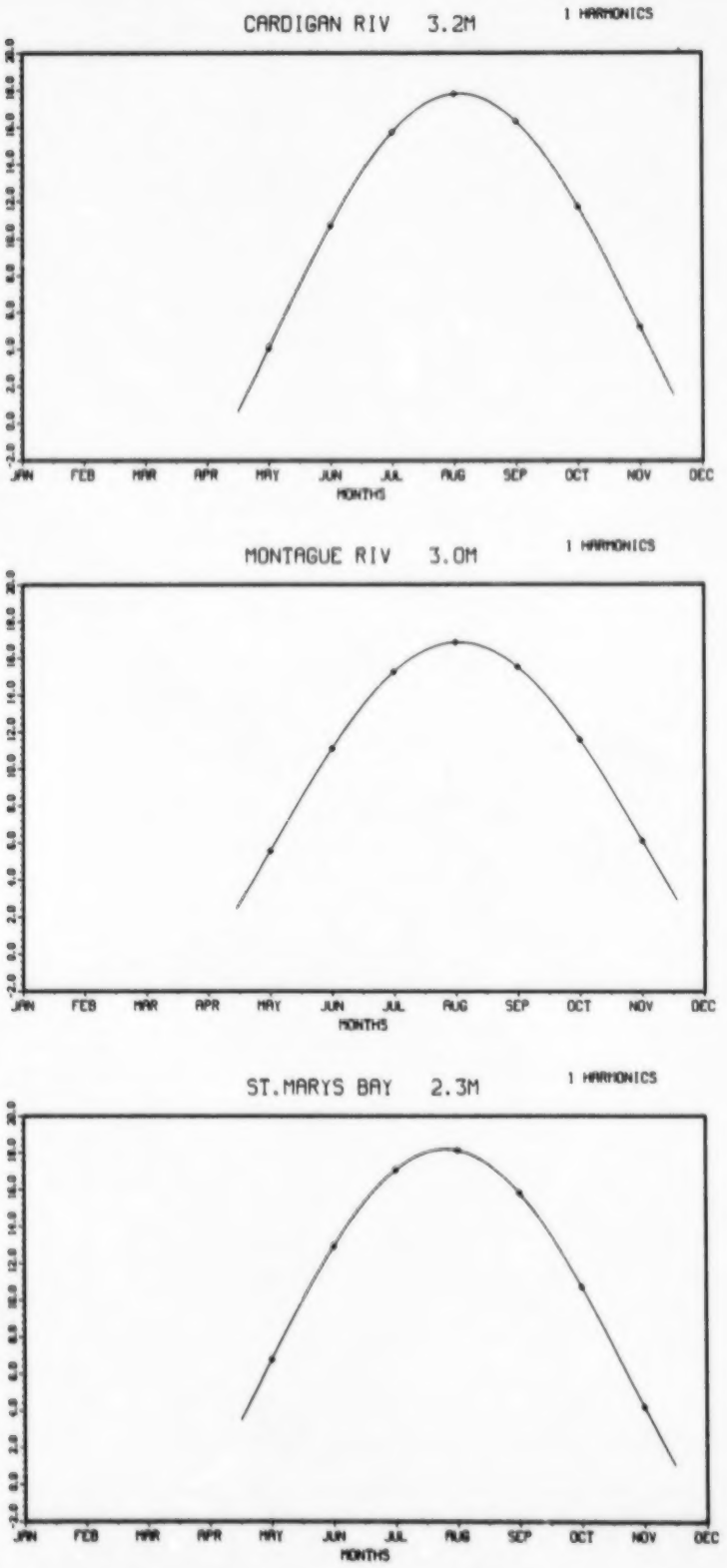

CARDIGAN RIV 3.2M
1 HARMONICS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
MONTAGUE RIV 3.0M
1 HARMONICS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
ST.MARYS BAY 2.3M
1 HARMONICS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS

Fig. A4. Sinusoidal fits of temperature data at mid-depth from Cardigan River, Montague River and St. Marys Bay.

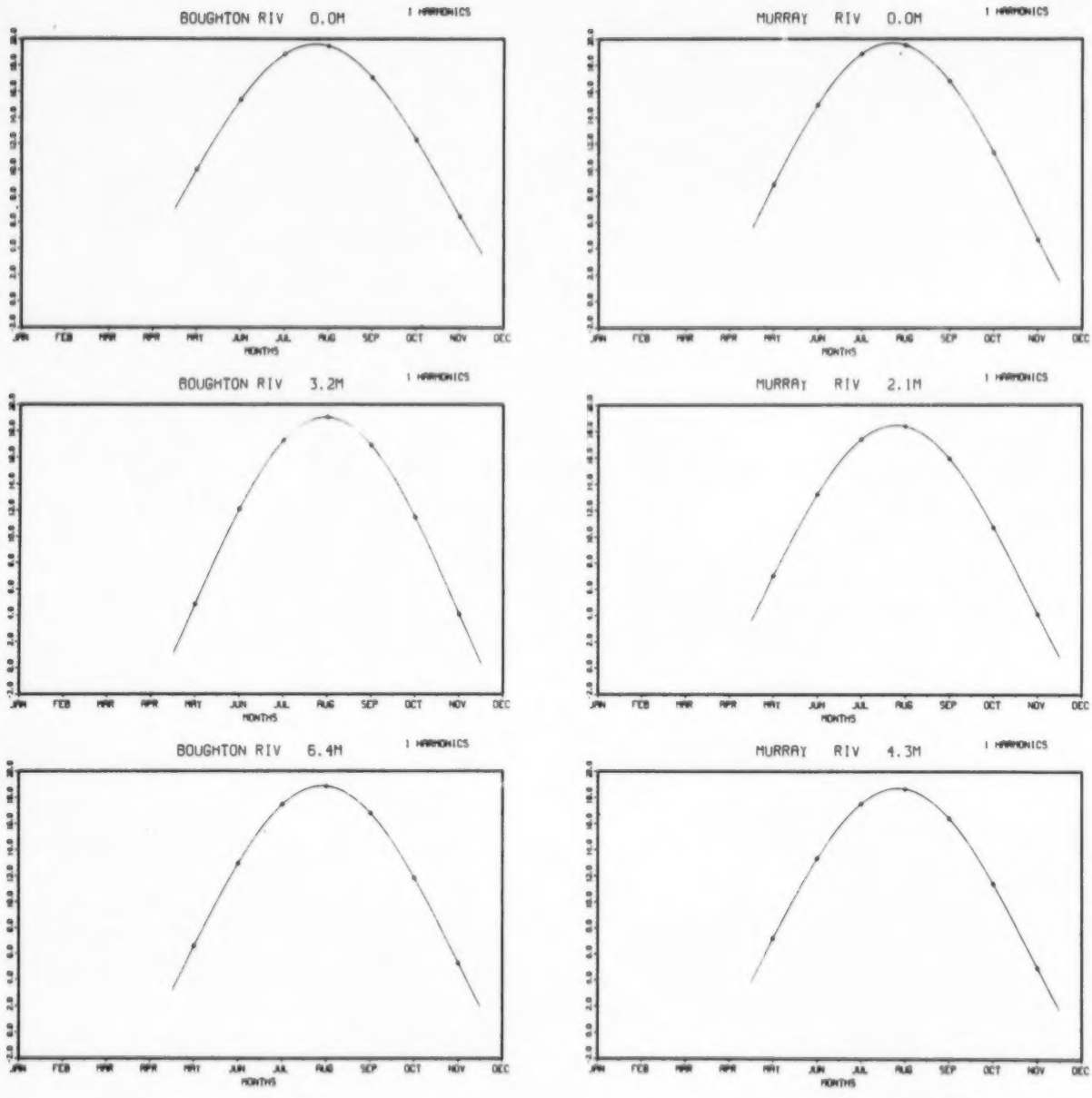


Fig. A5. Sinusoidal fits of temperature data from 3 depths at Boughton River and Murray River.

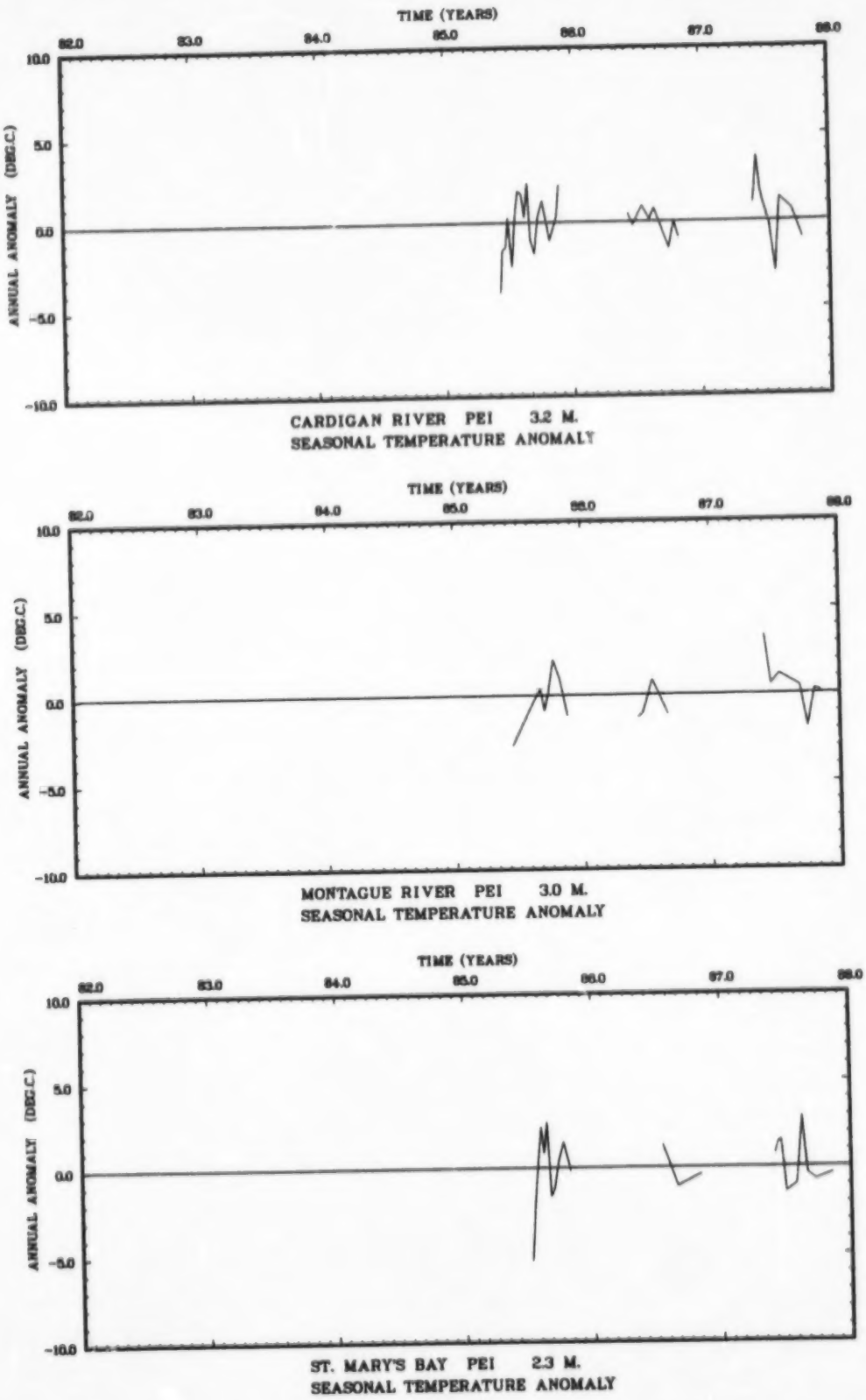


Fig. A6. Temperature anomalies at mid-depth for Cardigan River, Montague River and St. Marys Bay.

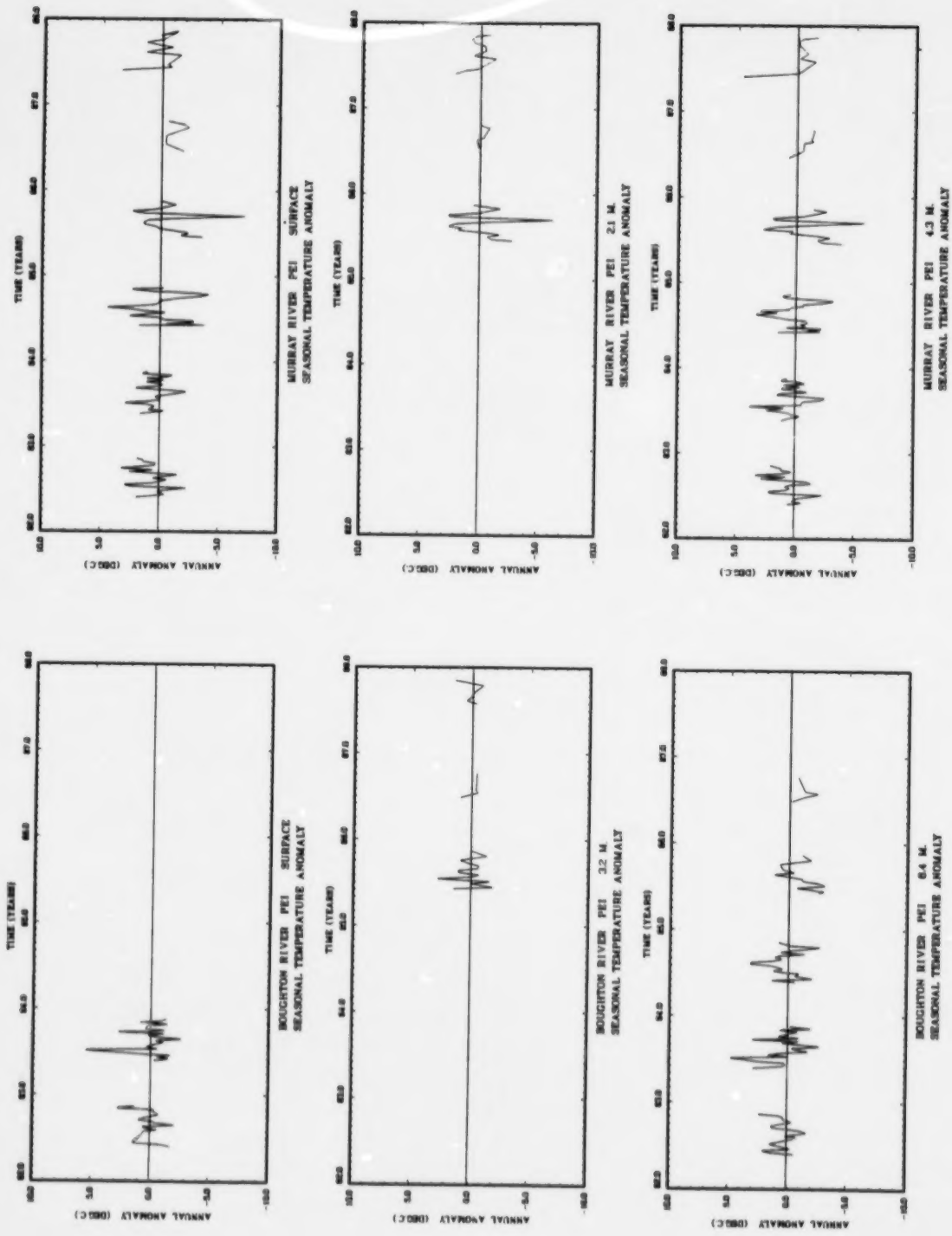
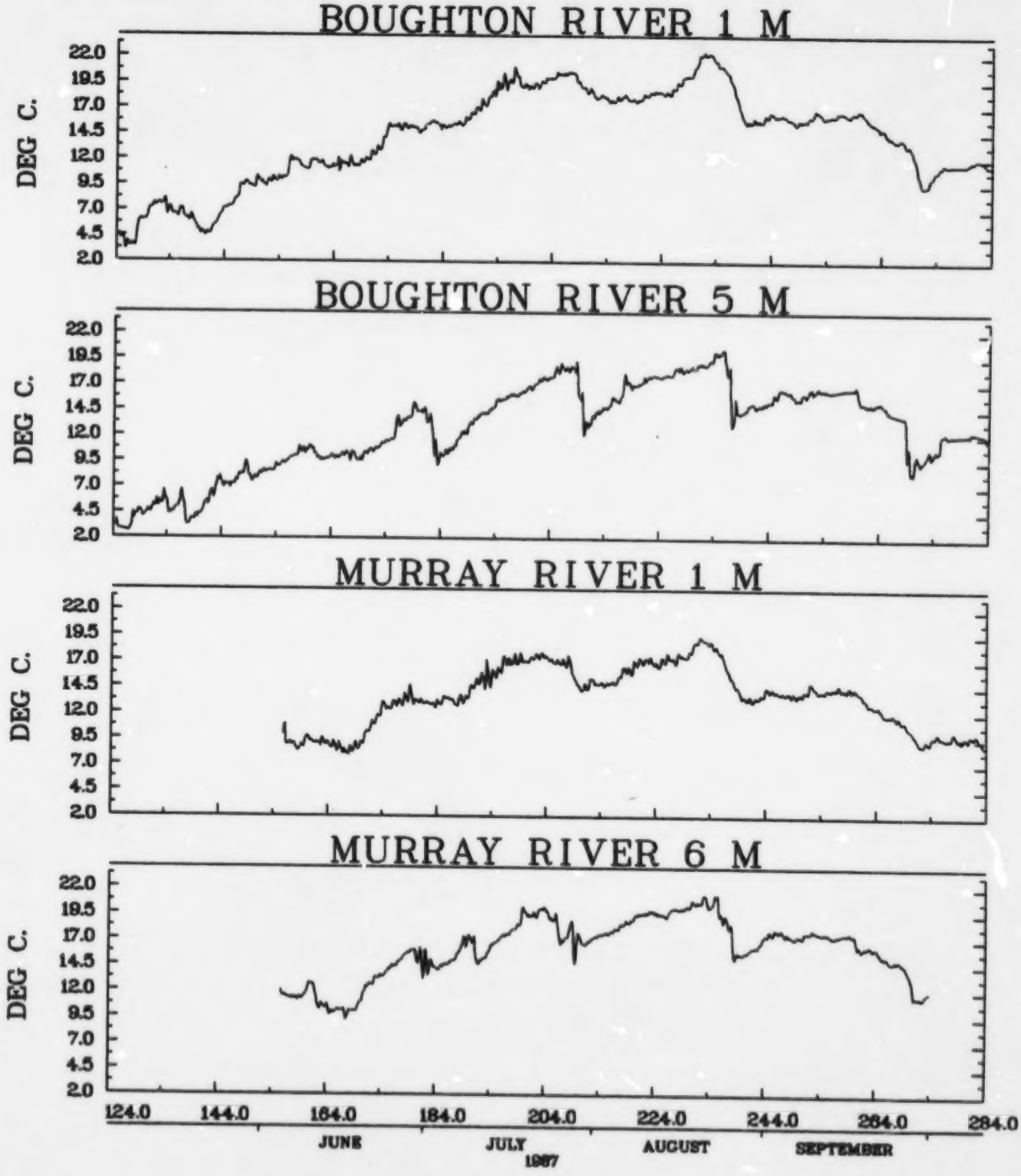


Fig. A7. Temperature anomalies for the Boughton and Murray Rivers.



PEI RYAN THERMOGRAPH DATA

Fig. A8. Temperature data from Ryan thermographs moored at Broughton and Murray Rivers during 1987.

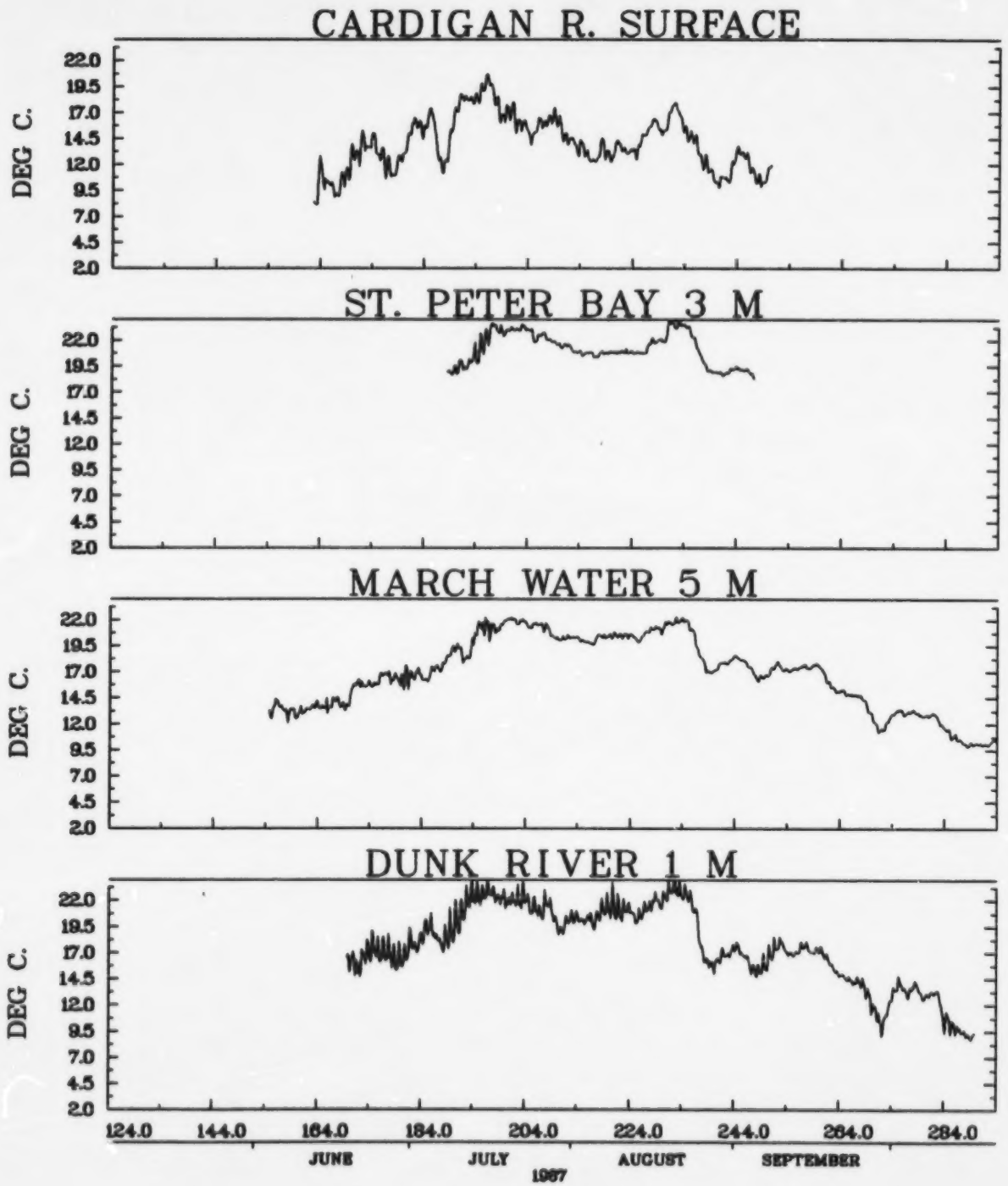


Fig. A9. Temperature data from Ryan thermographs moored at Cardigan River, St. Peters Bay, March Water, and Dunk River during 1987.

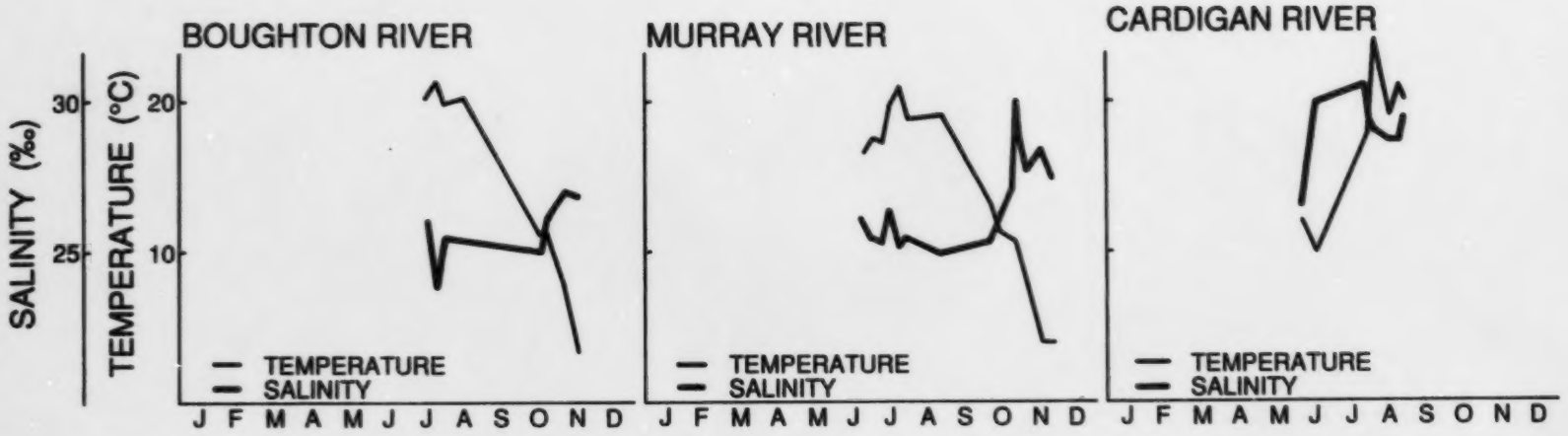


Fig. A10. Temperature and salinity data from the Boughton, Murray and Cardigan Rivers collected during 1987.